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Enzymatic bioconversion of kraft pulped and oxidative delignified sawdust from the Lagos Lagoon, Nigeria into fermentable sugars

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The major obstacle during pretreatment of lignocellulosic biomass centers mostly on the insufficient separation of lignin from cellulose that could further be converted into bioenergy and other useful chemicals. The choice of an optimum biomass pretreatment process depends on the digestibility of lignocellulosic material, cost-effectiveness and overall impact on the environment. Kraft pulp samples from sawdust wastes obtained along the Lagos Lagoon in Nigeria were delignified with 30% hydrogen peroxide and successively saccharified with *Trichoderma viride* cellulase during different incubation periods. Oxidative delignification of all Kraft pulped sawdust samples resulted in an increased degree of bioconversion relative to the saccharification of Kraft pulped sawdust. The highest percentage increase in saccharification during bioconversion of delignified Kraft pulped sawdust relative to degradation of only Kraft pulped sawdust was as follows: Sawdust from *R. heudelotii* showed an increase of 727% after 30 min of degradation with a 447% increase obtained from the same sawdust after an incubation period of 1 h. An increase of 323% was calculated for sawdust from *E. suaveolens* and *I. asarifolia* during a degradation period of 3 h with a 238% increase in glucose production from *M. excelsa* sawdust after a 6 h period of cellulase treatment.

Key words: Bioenergy, sawdust, *Trichoderma viride* cellulase, delignification, saccharification.

INTRODUCTION

During the past few decades the development of alternative and renewable energy resources became a topical issue with the combustion of fossil fuel described as having a negative effect on the environment (Luo et al., 2010; Erisman et al., 2011). Also considered as a negative environmental issue is the accumulation of increased volumes of solid waste of which the organic part is a major section with lignocellulose the foremost structural component of these organic waste materials (Ashori and Nourbakhsh, 2010). The development of lignocellulose waste as a renewable energy resource requires the conversion thereof into fermentable sugars such as glucose. Enzymatic catalyzed conversion of waste cellulose into glucose is considered as an environmental friendly means of developing lignocellulosic materials as a renewable energy resource.

Lignin, a biopolymer with a complex molecular structure is the major constituent of plant secondary cell walls, and accounts for about 10 to 35% of total plant dry mass. The function of lignin is to keep various cellulose layers in lignocellulose materials together (Sun et al., 2002) although the presence and amount of lignin in biomass

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seriously impede the enzymatic hydrolysis of the carbohydrate portion of lignocellulosic biomaterial. In the bioenergy development options, crystalline cellulose pose a highly resistant trend to hydrolysis as cellulose elementary fibrils are densely packed and coated with lignin to form a lignin-cellulose matrix. The matrix hinders the hydrolysis of cellulose into fermentable sugars, thereby making delignification a veritable pretreatment option (Himmel et al., 2007). Delignification of solid biomass is a procedure that is a determining step in the utilization of lignocellulosic biomaterials as a renewable energy resource for the production of bioethanol (Alvira et al., 2010). The goal of lignocellulosic pretreatment is to ensure the alteration of lignin-cellulose complex, extensive reduction of cellulose crystallinity and increase the porosity and surface area of lignocellulosic biomaterials to improve the efficiency of enzymatic hydrolysis of cellulosic materials into fermentable sugars (Sticklen, 2008; Galbe and Zacchi, 2007). Chemical pretreatments, besides physical procedures, such as oxidative delignification is a procedure initiated purely by chemical reactions that disrupt the lignin-carbohydrate complex thereby releasing the cellulose component for maximum enzymatic digestibility and subsequent conversion into fermentable sugars (Banerjee et al., 2011).

Sawdust pollution is a major concern in Lagos, Nigeria as many wood mills are located along the lagoon. During chopping of trees by the local population for manufacturing of wood products huge volumes of sawdust are produced and due to a lack in pollution management these biomass waste accumulates on the banks of the lagoon. To a certain extent this solid waste ends up in the water of the lagoon disturbing the natural eco-system. Effects of sawdust pollution on the Nigerian Lagos lagoon has been conducted and the results showed that sawdust extract of commercial hardwood species namely like *Khaya ivorensis*, *Mitragyna ciliata* and *Triplochiton scleroxylon* enhanced the germination of fungal spores in the water bodies, leading to adverse effects on the aquatic habitat (Akpata, 1986). The alteration of aquatic life environment has been reported on the influence of sawdust on the benthic macro invertebrates in strategic Nigerian rivers, leading to a complete extinction of economic aquatic species (Arimoro and Osakwe, 2006). Leachates of sawdust arising from the prolonged decomposition of wood natural organic substances (lignin, extractives, resins and fatty acids) when in contact with ground water channels have led to a sharp decline in water quality thus pose a serious threat to the Nigerian inland waters with adverse effect on economic and social activities (Akachukw, 2000; Akpata and Ekundayo, 1982; Akpata and Ekundayo, 1983). Currently the most popular means of eliminating the excess lignocellulose waste in Nigeria is combustion which aggravates air pollution with negative effects on the local populations' health (Abulude, 2006).

As an alternative to combustion the sawdust residuals have been investigated for bioconversion into fermentable sugars by *Trichoderma viride* cellulase. The utilization of wood waste (sawdust) as a renewable bioenergy resource will help to curb the environmental issues associated with indiscriminate dumping and burning of sawdust thereby leading to an improvement in economic and social activities. Sawdust samples from 20 different trees along the Lagos Lagoon have been collected, Kraft pulped and finally exposed to oxidative delignification with hydrogen peroxide (H_2O_2) in order to maximally remove the residual lignin content. These delignified celluloses were finally saccharified by *T. viride* cellulase with the relative amount of fermentable sugars released during degradation, determined. The identification of the wood waste species used in this study was carried out at the Forestry Research Institute of Nigerian (FRIN) while the Kraft pulping was performed at the Federal Institute of Industrial Research, Oshodi, Nigeria (FIIRO) (Ndukwe et al., 2009).

MATERIALS AND METHODS

Wood samples and cellulase enzymes

T. viride cellulase obtained from Duchefa, the Nederlands was dissolved in 0.40 ml Tris (hydroxymethyl) aminomethan (0.005 M) buffer, pH 4.5, at a concentration of 10.0 $mg \cdot ml^{-1}$. The common Nigerian names and botanical names (in brackets) of sawdust bioconverted during this investigation are as follows (Ndukwe et al., 2009): Erunobo (*Erythropleum suaveolens*), Okilolo (*Symphona globulifera*), Erimado (*Ricindendron heudelotii*), Oporoporo (*Pterygota macrocarpa*), Iroko (*Milicia excels*), Odoko (*Ipomoea asarifolia*), Abura (*Hallea ciliate*), Itara (*Sacoglottis gabonensis*), Akomu (*Pycnanthus angolensis*), Afara (*Terminalia superb*), Ofun (*Avicennia germinans*), Obeche (*Triplochiton scleroxylon*), Akun (*Uapaca guineensis*), Opepe (*Nauclea diderrichii*), Masonia (*Masonia altissima*), Agba (*Entada gigas*), Some (*Ceiba pentadra*), Mahogany (*Khaya Ivorensis*), Eki-Eki (*Lophira alata*) and Itako (*Strombosia pustulata*).

Cellulose pretreatment

To ensure an initial constant and similar cellulose mass for all cellulosic waste during the enzymatic bioconversion the sawdust samples were dehydrated at 105°C (Ndukwe et al., 2009). The air dried samples (2 kg, 2.8 to 5.0 mm particle size) were subjected to Kraft-pulping (350 g NaOH and 140 g Na_2S dissolved in 8 L water) and delignified in a rotary steel digester at 170°C at a pressure of 200 kPa for 1.45 h at a cooking liquor to wood ratio of 4:1 (Neto et al., 2002). After pre-treatment these delignified cellulose fibers were washed with deionized water until free of the Kraft reagents. The pulp air dried samples of partially delignified cellulose were then treated with a domestic blender to regain their original sawdust particle size.

To ensure maximum lignin free cellulose fiber the Kraft pre-treated sawdust materials (10 g) have been exposed to hydrogen peroxide (30%:60 ml) at a temperature of 40°C for 30 min. These pretreated and decolourized cellulose fibers were washed with deionized water until free of hydrogen peroxide and dried at 105°C until a constant mass was recorded which was finally treated with a

domestic blender to ensure the original particle size (Ndukwe et al., 2009).

Cellulase incubation and analytical methods

Kraft pulped sawdust samples as well as sawdust samples exposed to both delignification procedures (10 mg) were mixed separately in triplicate with 0.40 ml Tris (hydroxymethyl aminomethan, 0.005 M) buffer solution, pH 4.5. The enzymatic catalyzed hydrolysis was carried out with 100 ul of a *T. viride* cellulase solution (10.0 $mg.ml^{-1}$) at an incubation temperature of 40°C for a period of 0.5 h, 1.0 h, 3.0 h and 6.0 h. The amount of total reducing sugars released during cellulase action was determined by the dinitrosalicyclic acid (DNS) method at 546 nm using glucose as a standard (Miller, 1959). The amount of reducing sugars released from all the wood waste materials during the two delignification procedures, prior to cellulase incubation have also been determined. During these sugar determinations the cellulase enzyme was not added to the cellulose samples, instead the volume of enzyme (100 ul) was replaced with the buffer solution. These control sugar values have been subtracted from the sugar values obtained from the delignified cellulose degraded with *T. viride* cellulase.

RESULTS AND DISCUSSION

Environmental pollution and the development of renewable energy resources would become more topical as existing waste management procedures fail to deal effectively with increasing volumes of solid waste and the effect of fossil fuel combustion continues to have a negative impact on the environment. The huge amounts of sawdust produced annually along the Lagos Lagoon in Nigeria are a concern as it impacts negatively on the local eco system. These volumes of organic waste however also offer a major opportunity for the development of bioenergy as lignocellulosic waste can be converted into fermentable sugars. Similar bioconversion procedures have already been address and performedusing cellulase enzymes to hydrolyze cellulose into glucose (Sreenanth and Jeffries, 2000; Bothast and Schlicher, 2005). A major obstacle in the degradation of cellulosic waste is the association of cellulose with lignin a natural compound keeping various cellulose chains together (Kong et al., 1992). To make cellulose more susceptible for cellulase catalyzed degradation it is important to purify the cellulose from lignin and Kraft pulping has been applied in this respect to many lignocellulosic waste such as *Eucalyptus* wood (Villa et al., 2011), rice straw (Rodriguez et al., 2008) as well as aspen and spruce (Correia and Ray, 2005). Oxidative delignification is another procedure for the effective removal of lignin from cellulose thus renders cellulose more susceptible for cellulase catalyzed degradation. The effectiveness of this process has been illustrated during the cellulase catalyzed saccharification of oxidative delignified lignocellulosic waste from flax (Petrova et al., 2003) and pine wood (Efanov and Averin, 2004).

In order to address the environmental pollution along the Lagos Lagoon in Nigeria caused by excessive sawdust samples from twenty different trees have been delignified by Kraft pulping and successive oxidative delignification in order to increase the extent of *T. viride* cellulase catalyzed saccharification with the relative amount of glucose released from these sawdust materials compared.

Saccharification of delignified sawdust after 30 min of cellulase treatment

The amount of fermentable glucose released from Kraft pulped lignocellulose samples after 30 min of biodegradation with *T. viride* cellulase as indicated in Table 1 shows that *R. heudelotii* produced the lowest amount of glucose at a concentration of 1.1 $mg.ml^{-1}$. The highest degree of degradation was observed during the degradation of *N. diderrichii* at a concentration of 5.0 $mg.ml^{-1}$ that was 4.5 times higher than the lowest sugar concentration. The average sugar concentration obtained from these twenty Kraft pulped sawdust samples was calculated at a concentration of 2.3 $mg.ml^{-1}$ with ten sugar concentration higher than this average value. During the 30 min degradation procedure of lignocellulosic waste exposed to both Kraft pulping and oxidative delignification the lowest concentration was calculated for glucose released from *M. excelsa* sawdust at a concentration of 3.8 $mg.ml^{-1}$. This sugar concentration was 3.6 times less than the highest amount produced from *E. gigas* at a concentration of 13.7 $mg.ml^{-1}$. Oxidative delignified Kraft pulped sawdust proved to be more susceptible for degradation than Kraft pulped sawdust not exposed to oxidative delignification. The minimum increase in sugar formation obtained from both delignification procedures compared to Kraft pulped sawdust is calculated at 29% for *N. diderrichi*. The maximum increase in sugar formation from the oxidative delignified Kraft pulped materials during 30 min of degradation was calculated at 728% for *R. heudelotti.* An average sugar value of 7.8 $mg.ml^{-1}$ was calculated for all twenty samples with seven sawdust samples released sugars at a concentration higher than this average amount.

Saccharification of delignified sawdust after 1 h of cellulase treatment

After 1 h (Table 2) of *T. viride* cellulase treatment the highest sugar concentration of 6.9 $mg.ml^{-1}$ was calculated for Kraft pulped sawdust from *N. diderrichii* that was 4.6 times higher than the lowest sugar concentration obtained from *M. excelsa* sawdust at a value of 1.5 $mg.ml^{-1}$. An average sugar concentration of 3.4 $mg.ml^{-1}$ was calculated for all samples which resulted in seven sawdust samples with sugar concentrations higher than this average value. During degradation of Kraft pulped

Table 1. The relative saccharification of oxidative delignified Kraft pulp cellulose waste with *Trichoderma viride* cellulase after 30 min of biodegradation.

Lignocellulosic wood waste (sawdust)	Glucose concentration ($mg.ml^{-1}$) of Kraft pulped biodegraded cellulose	Glucose concentration ($mg.ml^{-1}$) of Kraft pulped and oxidative delignified biodegraded cellulose	Increase (%) in glucose production from oxidative delignified and Kraft pulped cellulose relative to Kraft pulped cellulose only
E. suaveolens	1.5	12.3	677
S. globulifera	1.2	5.6	375
R. heudelotii	1.1	7.4	727
P. macrocarpa	1.5	6.6	320
M. excelsa	1.2	3.8	218
I. asarifolia	2.1	6.5	20
H. ciliata	2.8	5.5	99
S. gabonensis	1.3	6.9	424
P. angolensis	3.1	6.4	111
T. superba	2.9	11.3	290
A. germinans	1.2	5.2	335
T. scleroxylon	2.4	7.2	203
U. guineensis	3.3	8.1	146
N. diderrichii	4.9	6.4	29
M. altissima	2.1	7.2	244
E. gigas	2.6	13.7	426
C. pentadra	2.9	10.1	240
K. ivorensis	2.7	7.1	162
L. alata	1.9	11.1	480
S. pustulatas	3.7	8.5	270

sawdust that was oxidatively delignified the highest sugar concentration was obtained from *E. suaveolens* at a concentration of 14.3 $mg.ml^{-1}$ that was 3,1 times higher than the lowest concentration of 4.6 $mg.ml^{-1}$ released during the degradation of *M. excels* sawdust. The average sugar concentration obtained during bioconversion of these Kraft pulped sawdust samples that were also oxidative delignified resulted in a value of 9,3 $mg.ml^{-1}$ with eight samples producing sugars at a concentration higher than average value of sugar formation. The highest percentage increase in degradation of sawdust materials exposed to both Kraft pulping and oxidative delignification relative to these materials only Kraft pulped during a 1 h incubation period was calculated at 447% for *R. heudelotii* while the lowest percentage increase was obtained at 24% with sawdust from *N. diderrichii*.

Saccharification of delignified sawdust after 3 h of cellulase treatment

When the twenty Kraft pulped sawdust (Table 3) samples were incubated with *T. viride* cellulase during a period of 3 h a maximum glucose concentration of 10.3 $mg.ml^{-1}$ was released from *T. scleroxylon* sawdust that was 5 times higher than the lowest sugar concentration of 2.1 $mg.ml^{-1}$ released from *M. excels* sawdust. With the sawdust exposed to both delignification procedures the maximum sugar concentration of 14.8 $mg.ml^{-1}$ was released from *E. suaveolens* that was 2.1 times higher than the lowest concentration released from *M. excelsa* sawdust producing sugars at 6.9 $mg.ml^{-1}$. The average concentration of sugars released by the Kraft pulped sawdust samples was 5.2 $mg.ml^{-1}$ with 6 samples resulted in values higher than the average value whilst the samples exposed to both delignification procedures resulted in an average sugar concentration of 11.32 $mg.ml^{-1}$ with seven samples resulted in sugar concentrations higher than this average sugar value. The highest percentage increase in sugar formation released from sawdust samples exposed to both delignification procedures compared to the sugar yield released by Kraft pulped sawdust is 323% experienced by both *E. suaveolens* and *I. asarifolia* cellulose. The lowest percentage increase in sugar formation during 3 h of incubation was 7% for both *T. scleroxylon* and *N. diderrichii* cellulose.

Saccharification of delignified sawdust after 6 h of cellulase treatment

All sawdust samples exposed to Kraft pulping as well as Kraft and successive oxidative delignification showed an

Table 2. The relative saccharification of oxidative delignified Kraft pulp cellulose waste with *Trichoderma viride* cellulase after 1 h of biodegradation.

Lignocellulosic wood waste (sawdust)	Glucose concentration ($mg.ml^{-1}$) of Kraft pulped biodegraded cellulose	Glucose concentration ($mg.ml^{-1}$) of Kraft pulped and oxidative delignified biodegraded cellulose	Increase (%) in glucose production from oxidative delignified and Kraft pulped cellulose relative to Kraft pulped cellulose only
E. suaveolens	2.7	14.2	427
S. globulifera	1.7	8.1	368
R. heudelotii	1.9	10.7	447
P. macrocarpa	1.7	8.8	408
M. excelsa	1.5	4.6	207
I. asarifolia	2.4	8.7	251
H. ciliata	5.1	8.1	62
S. gabonensis	2.5	9.8	287
P. angolensis	3.3	8.8	162
T. superba	3.9	11.5	189
A. germinans	2.7	5.2	87
T. scleroxylon	6.6	9.9	48
U. guineensis	4.6	9.2	96
N. diderrichii	6.9	8.6	24
M. altissima	2.6	8.1	204
E. gigas	3.1	13.9	113
C. pentadra	3.1	10.0	226
K. ivorensis	3.0	8.8	188
L. alata	5.1	12.2	137
S. pustulatas	4.3	8.7	102

increase in sugar production during increasing incubation periods when degraded with *T. viride* cellulase. The maximum amount of sugar released from Kraft pretreated sawdust during 6 h of degradation (Table 4) with *T. viride* cellulase was obtained from *L. alata* at a concentration of 13.4 $mg.ml^{-1}$ and the minimum sugar concentration at 2.3 $mg.ml^{-1}$ obtained from *M. exelsa* cellulose. Sawdust from *L. alata* exposed to both delignification procedures produced the maximum sugar concentration of 14.5 $mg.ml^{-1}$ whilst the lowest sugar concentration released by *M. excelsa* cellulose was at a concentration of 7.7 $mg.ml^{-1}$. A minimum increase of sugar production (2%) was observed when sawdust from *N. diderrichii* was exposed to these two delignification procedures with the maximum increase of 238% calculated during the degradation of *M. excels* cellulose. The average sugar concentration obtain from the Kraft pretreated sawdust samples after 6 h of incubation was 8.4 $mg.ml^{-1}$ and from the cellulosic materials exposed to both delignification procedures equal to a concentration of 12.1 $mg.ml^{-1}$. In both cases a total of ten samples resulted in concentrations higher than the average values.

Maximum saccharification of delignified sawdust

The various pretreated biomass materials released different amounts of sugars during *T. viride* cellulase catalyzed bioconversion with the maximum amount of sugar produced summarized in Figure 1. Maximum sugar formation from Kraft pulped materials during 0.5 h of incubation was obtained from *N. diderrichii* hardwood at a concentration of 4.9 $mg.ml^{-1}$ while a maximum concentration of 13.7 $mg.ml^{-1}$ was released from *E. giga* cellulose during the same incubation period when this cellulose material was exposed to both Kraft pulping and oxidative delignification. After 1h of enzymatic incubation Kraft pretreated lignocellulose from *N. diderrichii* resulted in the highest sugar concentration of 6.9 $mg.ml^{-1}$ with a maximum concentration of 14.2 $mg.ml^{-1}$ released from *E. suaveolens* lignocellulose when exposed to both Kraft pulping and oxidative degradation. During 3 h of cellulase catalyzed degradation the Kraft pretreated lignocellulosic material from *T. scleroxylon* resulted in the highest sugar concentration of 10.3 $mg.ml^{-1}$ whilst a maximum sugar concentration of 14.8 $mg.ml^{-1}$ was released from *E. suaveolens* lignocellulose after exposure to both Kraft and oxidative delignification procedures. Kraft pretreated lignocellulosic material from *L. alata* resulted in the highest sugar concentration of 13.4 $mg.ml^{-1}$ after 6 h of cellulase catalyzed incubation with lignocellulosic materials from the same source also resulted in the maximum sugar concentration of 15.0 $mg.ml^{-1}$ after the same incubation period when delignified by both

Table 3. The relative saccharification of oxidative delignified Kraft pulp cellulose waste with *Trichoderma viride* cellulase after 3 h of biodegradation.

Lignocellulosic wood waste (sawdust)	Glucoseconcentration ($mg.ml^{-1}$) of Kraft pulped biodegraded cellulose	Glucose concentration ($mg.ml^{-1}$) of Kraft pulped and oxidative delignified biodegraded cellulose	Increase (%) in glucose production from oxidative delignified and Kraft pulped cellulose relative to Kraft pulped cellulose only
E. suaveolens	3.5	14.8	323
S. globulifera	3.4	11.2	227
R. heudelotii	2.6	10.9	311
P. macrocarpa	3.4	9.9	186
M. excelsa	2.1	6.9	232
I. asarifolia	2.8	12.1	323
H. ciliata	8.7	10.3	18
S. gabonensis	2.8	10.1	256
P. angolensis	5.1	11.3	124
T. superba	4.5	12.7	179
A. germinans	2.8	7.7	169
T. scleroxylon	10.3	11.1	7
U. guineensis	5.6	13.9	147
N. diderrichii	9.9	10.6	7
M. altissima	5.1	12.1	135
E. gigas	3.7	14.1	275
C. pentadra	7.1	11.7	63
K. ivorensis	4.3	10.1	132
L. alata	8.5	14.4	69
S. pustulatas	8.3	10.5	26

procedures.

Maximum increase in saccharification of delignified sawdust

During all incubation periods each of the lignocellulosic materials were increasingly saccharified by *T. viride* cellulase after exposure to both delignification procedures compared to delignification by Kraft pulping only. The maximum percentage increase of sugar formation is decreased during extended periods of saccharification as reflected in Table 2. After 0.5 h of cellulase treatment a maximum increase of 728% was released from *R. heudelotti* lignocellulose materials with a 447% increase in sugar formation from the same source after 1.0 h of incubation. A maximum percentage increase of 275% was calculated for lignocellulosic materials released from *E. gigas* cellulosic materials during the 3 h period of incubation while lignocellulosic materials from the same source resulted in the maximum percentage increase of 123% after 6 h of treatment with cellulose from *T. viride*.

Lignocellulosic biomass represents the largest renewable reservoir of potentially fermentable carbohydrates on earth (Ahmadi et al., 2010) with these materials containing almost 75% of cellulose and hemicelluloses which cannot be easily saccharified due to its recalcitrant nature. Extensive research has been done on the bioconversion of lignocellulosic wastes into fermentable sugars (Louime and Uckelmann, 2008) with the potential of organic waste as an potential renewable energy resource described (Van Wyk, 2001). Delignification procedures remove the lignin component of lignin-cellulose thus promoting hydrolysis and improving the glucose recovery from cellulose and cellulase catalysed degradation of cellulosic materials is a promising method to obtain high yields of fermentable sugars (Chinedu et al., 2010).

Conclusion

The development of alternative and renewable energy resources together with the management of increasing volumes of solid waste would become more topical as the effect of fossil fuel combustion is experienced through climate change that will affect many global communities. Together is the extensive production of organic solid waste which in many parts of the globe such as along the Lagos Lagoon in Nigeria is accumulating due to a lack of effective management procedures. By converting the cellulose component of organic waste into fermentable

Table 4. The relative saccharification of oxidative delignified Kraft pulp cellulose waste with *Trichoderma viride* cellulase after 6 h of biodegradation.

Lignocellulosic wood waste (sawdust)	Glucose concentration ($mg.ml^{-1}$) of Kraft pulped biodegraded cellulose	Glucose concentration ($mg.ml^{-1}$) of Kraft pulped and oxidative delignified biodegraded cellulose	Increase (%) in glucose production from oxidative delignified and Kraft pulped cellulose relative to Kraft pulped cellulose only
E. suaveolen	7.5	14.4	90
S. globulifera	5.8	11.2	94
R. heudelotii	6.6	12.5	88
P. macrocarpa	7.4	11.6	56
M. excelsa	2.3	7.7	238
I. asarifolia	7.7	11.6	50
H. ciliata	8.4	10.5	25
S. gabonensis	9.4	12.8	35
P. angolensis	10.5	12.4	18
T. superba	12.7	13.8	9
A. germinans	4.3	9.5	117
T. scleroxylon	10.3	11.4	10
U. guineensis	11.5	14.1	21
N. diderrichii	11.1	11.3	2
M. altissima	6.6	13.4	102
E. gigas	6.3	14.1	123
C. pentadra	10.8	12.4	14
K. ivorensis	6.8	12.1	76
L. alata	13.4	15.0	11
S. pustulatas	8.5	11.8	39

sugars could address both issues as a renewable energy resource such as bioethanol could be produced during the fermentation of glucose released during the saccharification of delignified waste cellulose. The degradation of Kraft and oxidative delignified sawdust from twenty different trees along the Lagos Lagoon in Nigeria resulted in the release of different sugar concentrations. Both delignification procedures resulted in an increased sugar formation relative to all sawdust samples when only exposed to Kraft pulping indicating that extensive delignification is an important prerequisite for the effective saccharification of lignocellulosic waste.

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